X-energy Introduction

NUPIC Vendor Meeting

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Reimagining Nuclear Energy

X-energy is reimagining nuclear's role in solving tomorrow's energy challenges

- Founded in 2009 out of Dr. Ghaffarian's desire to address the world's most serious energy challenges and make a lasting contribution to clean energy technology in the U.S. and around the world
- Leverages expertise from SGT, Inc.– 2nd largest engineering services contractor to NASA, and another prominent company founded & managed by Dr. Ghaffarian
- Funding of >$20M over the 7-year life of the company
- Nucleonics team, led by Chief Nuclear Officer Dr. Eben Mulder, leverages experience from pebble bed reactors around the world, including experience at AVR & THTR (Germany)

Dr. Kam Ghaffarian
Founder & CEO

"I began X-energy because the world needs energy solutions that are clean, safe, secure, and affordable. With so much at stake, we cannot continue down the same path."

-Dr. Kam Ghaffarian, Founder & CEO

The X-energy Design Approach

- Draw extensively from pebble bed and gas reactor design and operational experience spanning approximately 90 reactor years
- Combine lessons learned from previous and existing pebble bed reactor programs to ensure a licensable, low-risk design that can be brought to market in the shortest possible time
- Reduce complexity of previous designs in order to achieve a strong business case through a low cost design that does not compromise safety
- Incorporate reference data from Next Generation Nuclear Plant (NGNP) program to meet utility/user requirements, while ensuring NRC regulatory compliance

High Level Requirements

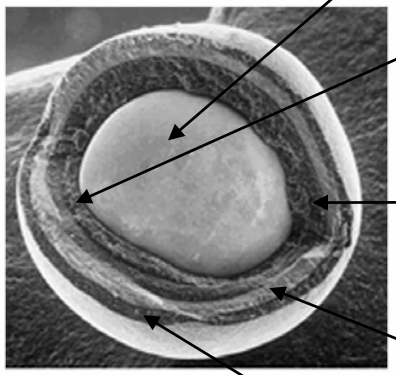
- Intrinsic safety (i.e. passive safety guaranteed by the laws of physics)
- Simplicity, safety, cost effectiveness, and proliferation resistance through a once through fuel cycle with online fuelling
- Produce high temperature steam (540 °C)
- Road transportability for components as far as possible
- Base load delivery with consequential load following
- Economically competitive with conventional nuclear and coal
- High level of modularization to minimize site work and construction times
- Provision for advanced fuel cycle development
- Design within proven technology readiness levels

Xe-100: Incorporated Design Principles

Principles followed meticulously in designing the coupled neutronics and thermo-fluid dynamics behavior of the Xe-100 nuclear system

TRISO Coated Particle for Fuel in Pebble

TRISO Coated Particle



FUNCTIONS: TRISO COATED PARTICLE

- **Fuel Kernel – ρ=10.4 g/cm^3; D=0.425 mm**
  - **Fission energy source**
  - **Retain short-lived radionuclides**
- **Buffer layer (porous carbon) – ρ=1.05 g/cm^3; T=0.100 mm**
  - **Void volume for fission gases**
  - **Accommodates fuel kernel swelling**
  - **Protect PyC and SiC layers from fission product recoil**
- **Inner Pyrocarbon (iPyC) – ρ=1.85 g/cm^3; T=0.040 mm**
  - **Diffusion barrier to fission products**
  - **Provide mechanical substrate for SiC deposition**
  - **Prevent Cl_2 from reaching kernel during SiC deposition**
- **Silicon Carbide (SiC) – ρ=3.2 g/cm^3; T=0.035 mm**
  - **Primary fission product barrier in all anticipated plant conditions**
  - **Load-bearing layer for TRISO particle**
- **Outer Pyrocarbon (oPyC) – ρ=1.85 g/cm^3; T=0.040 mm**
  - **Provide compressive stress on SiC during irradiation**
  - **Provide bonding layer with matrix graphite**
  - **Provide fission product barrier**

Pebble Fuel Zone: Functions

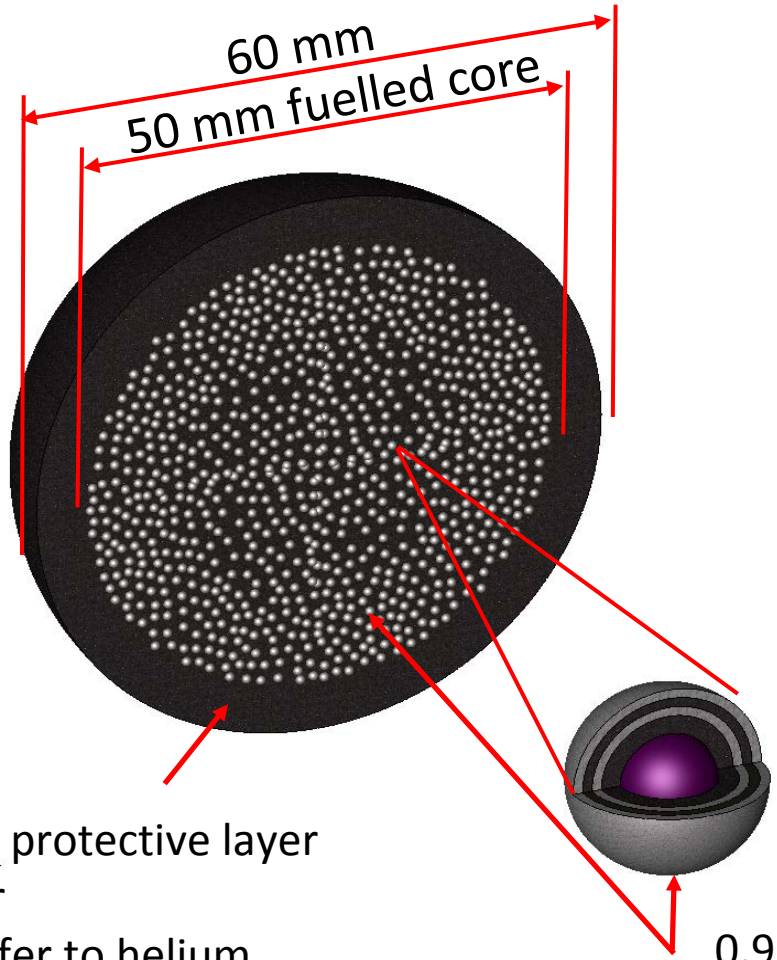
Pebble Fuel Zone

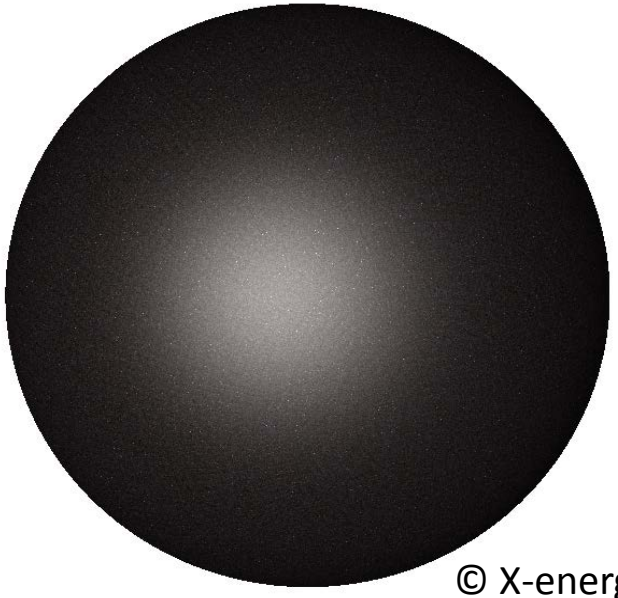
FUNCTIONS: PEBBLE FUEL ZONE

- **Form Fuel Zone – 25 mm Sphere**
  - **Contains statistically distributed TRISO coated particles with a 13-15% packing fraction in a fixed geometry**
- **Provide matrix graphite – Overcoating + filler graphite**
  - **Buffers TRISO particles when pressed**
  - **Neutron moderator during fission process**
  - **Retain radionuclides or resist diffusion of radionuclides in the low probability event of radionuclide escape**
  - **Provides thermal transport medium**
- **Provides muster on the surface**
  - **Helps to position the fuel zone within the fuel free shell**
  - **Provides seamless integration with fuel-free zone when pressed and processed**

Pebble Fuel-Free Zone: Function

Pebble – 60 mm Diameter Graphitic Fuel Sphere





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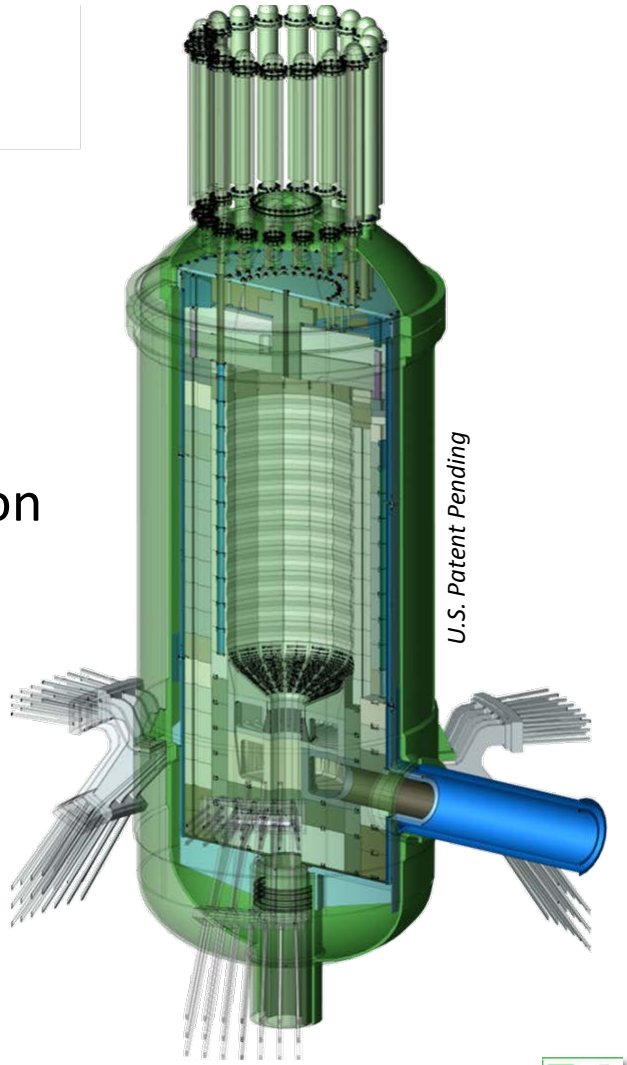
FUNCTIONS

- 5mm thick protective layer
- Moderator
- Heat transfer to helium

0.9 mm UCO coated particle
(± 23 000 TRISOs per pebble)

Xe-100: Unique Features

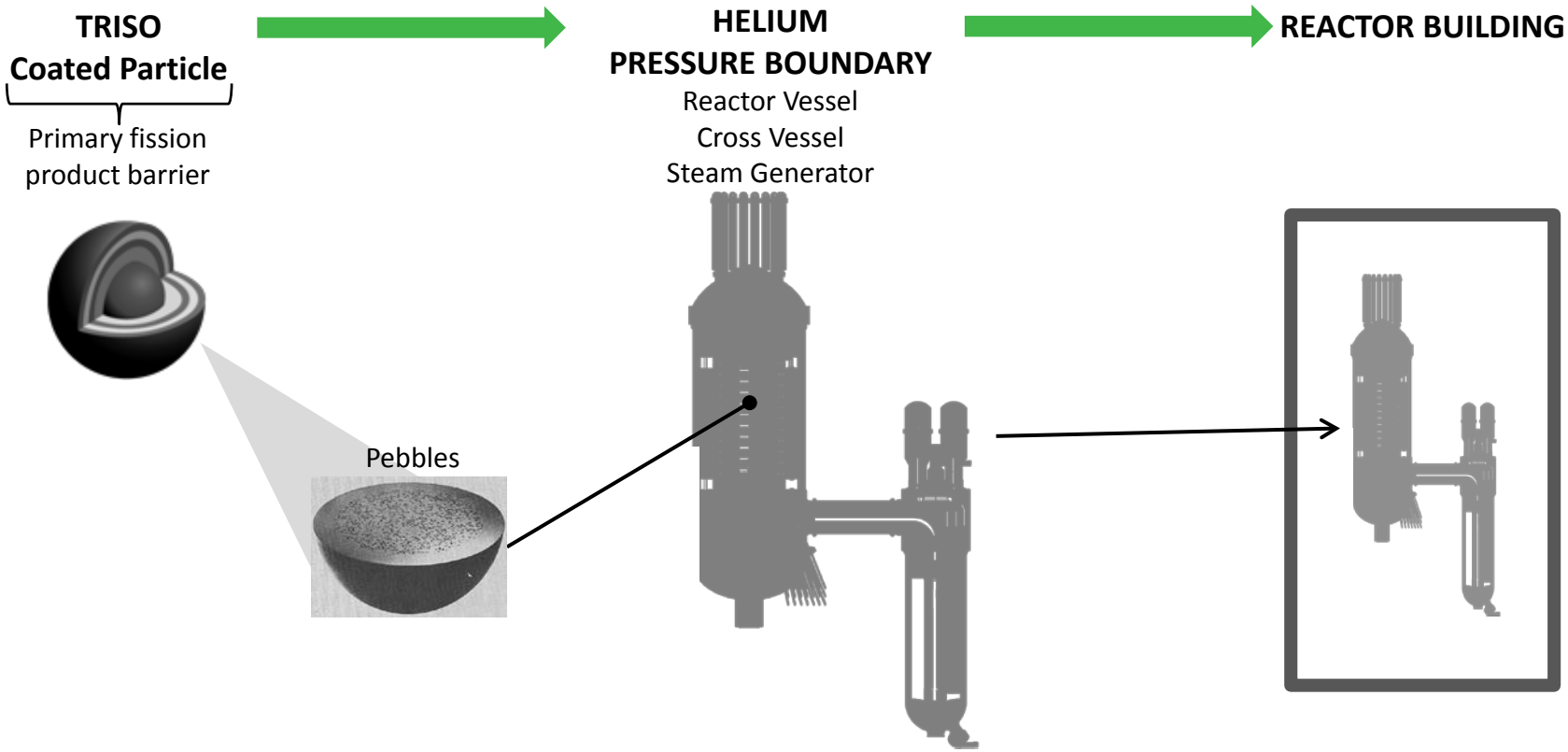
- Once-through (OTTO) on-line fueling
  - Reduced maintenance cost and frequency
  - Reduced potential for dust generation
- Reduced reactor length
- Simplified control and shutdown system
- Helium flow path
  - High pressure cold gas on outside
  - Serpentine gas flow impedes natural convection
- Graphite core structure layout
  - Reduced inter-block leakage flow
  - Reduced thermal stressing of graphite blocks
- Core barrel and Reactor Pressure Vessel (RPV)
  - Simple core barrel support system
  - Uniform core barrel and RPV temperatures
- Modular installation



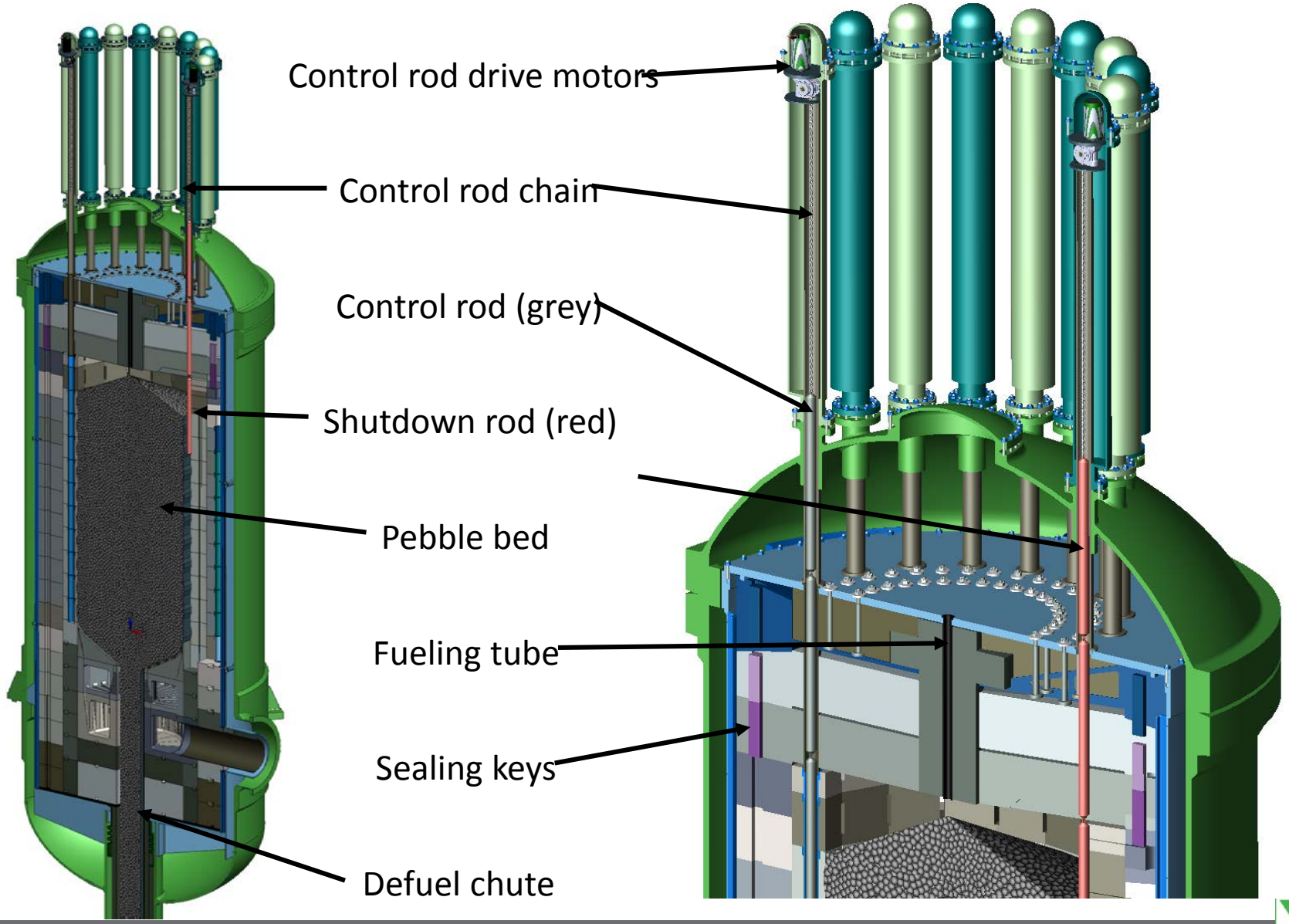
The Xe-100 Reactor

- The Xe-100 is a 125MW_{th} helium cooled power plant that features a LEU fuel cycle
- The heat source is based on pebble bed technology which has a proven **meltdown proof** core
- Heat transfer is via a proven helical coil steam generator
- The Xe-100 is a CO_2-free nuclear thermal power source that can be utilized for power generation, process heat applications, and water desalination
- Small size and modular construction result in relatively low cost

Safety: Concept of Functional Containment

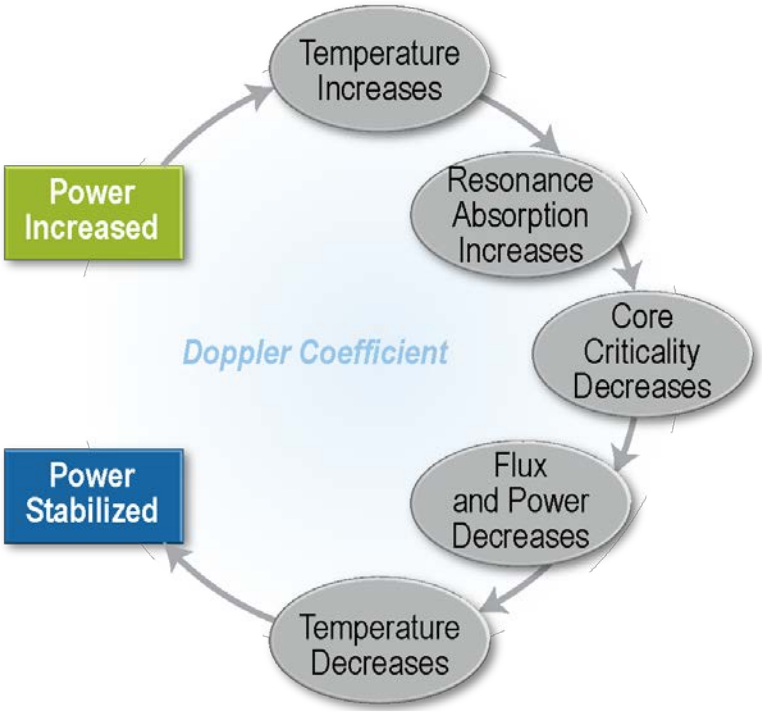


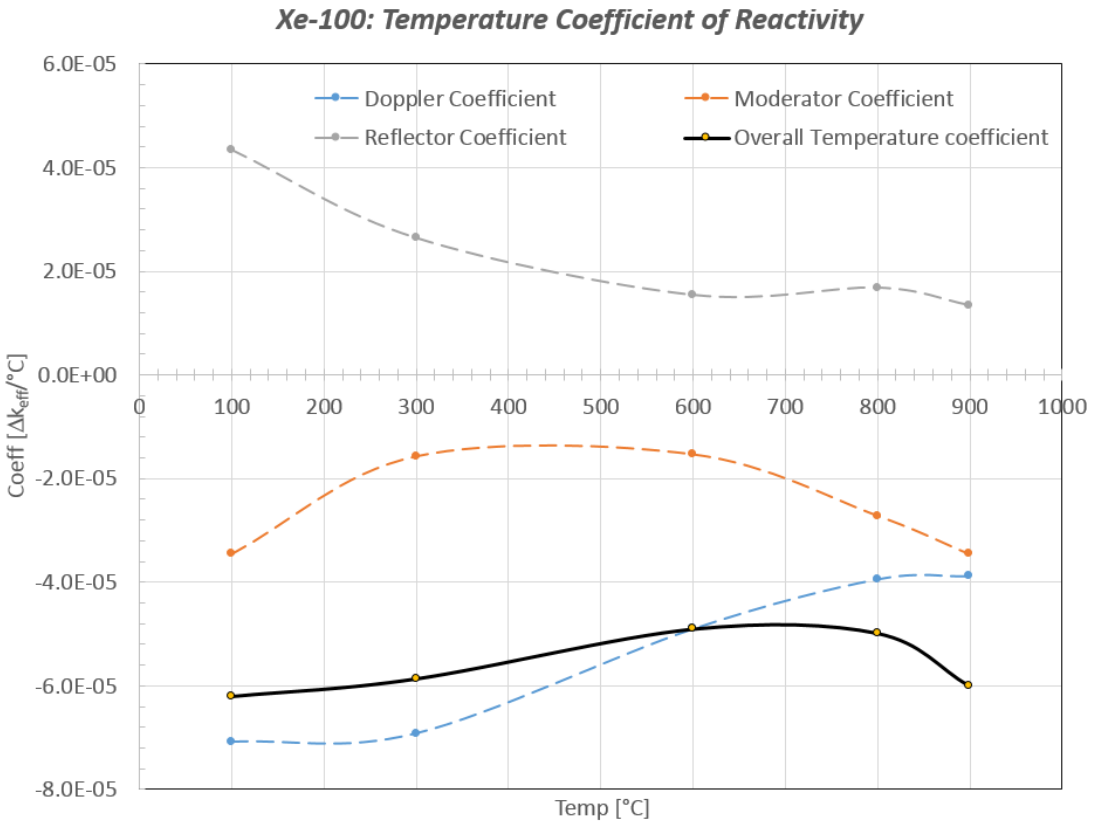
Xe-100: Incorporated Design Principles



Negative Temperature Coefficient

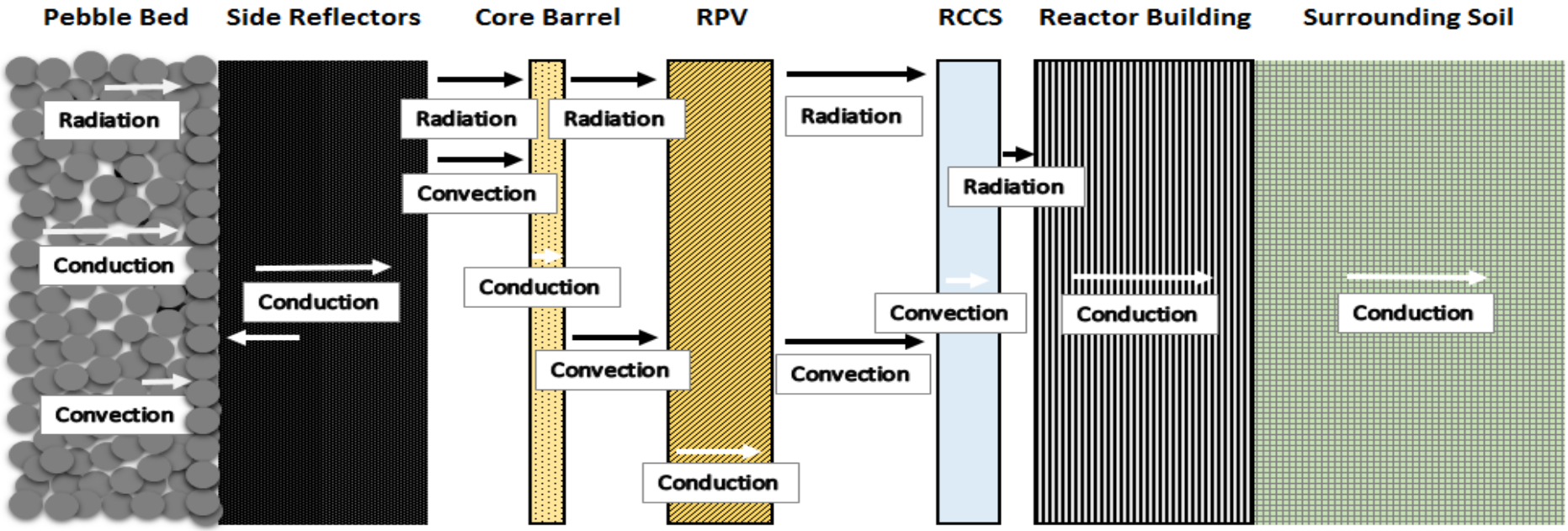
If the temperature increases, the nuclear chain reaction dies down due to overall negative temperature coefficient



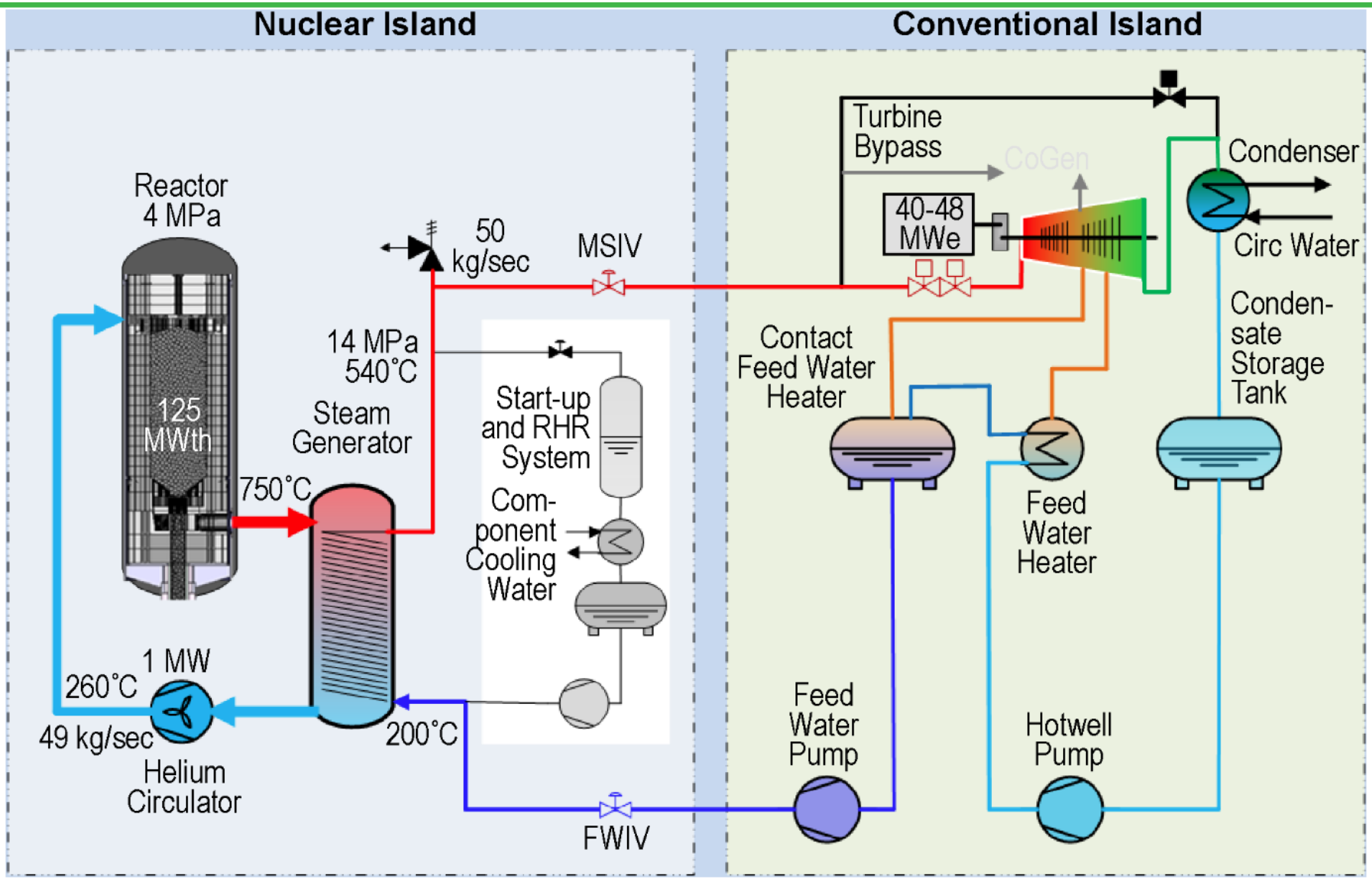


Passive Heat Removal

- During a loss of normal forced cooling, with or without helium pressure, core heat is removed passively:
  - Conduction through the pebbles and side reflector
  - Convection and thermal radiation to the core barrel and Reactor Pressure Vessel (RPV) to the reactor cavity cooling system (RCCS)
  - Normal heat removal through RCCS by natural convection
  - Conduction through the concrete to the environment if the RCCS is not available

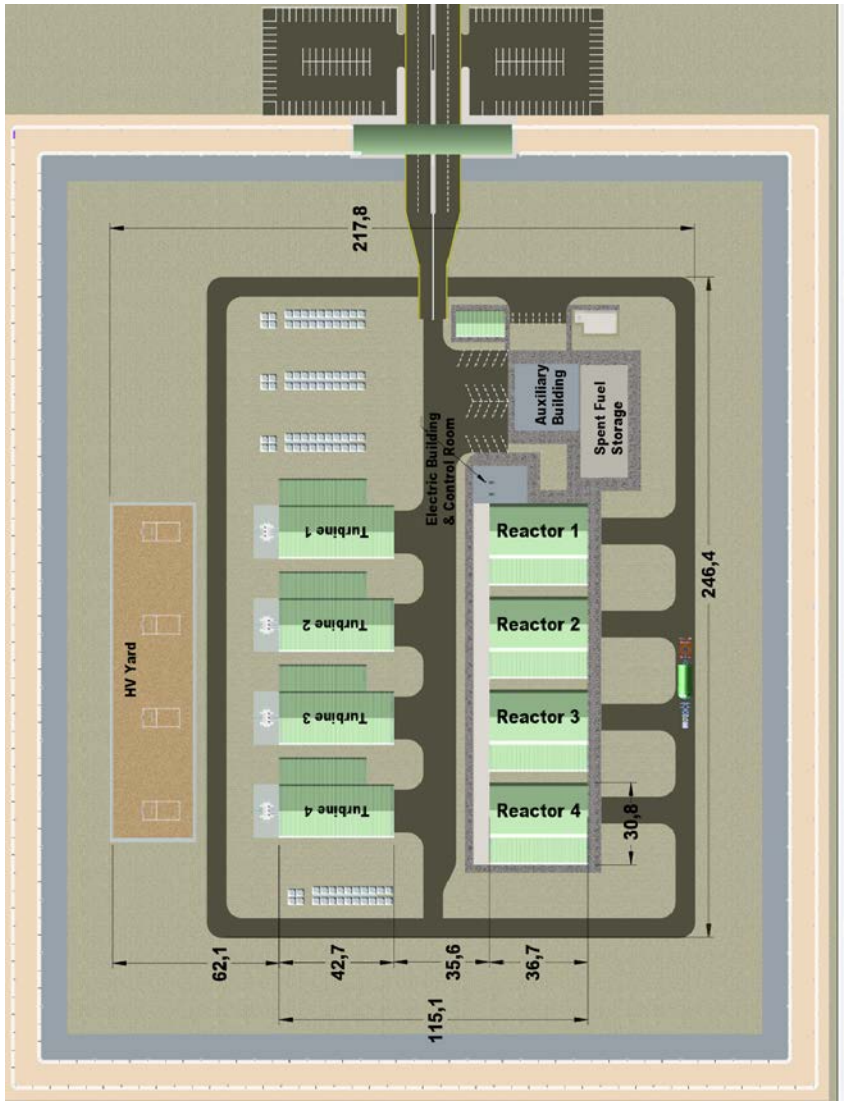


Electricity or Steam Production



Site Layout Considerations

- Optimizes safety by passively preventing melt down
- Underground reactor layout is possible
- Can be built in close proximity to existing infrastructure
- Modularity allows for variable power needs
- Grid independence capable



U.S. Department of Energy Endorsement

U.S. DOE Selects X-energy for Advanced Reactor Award

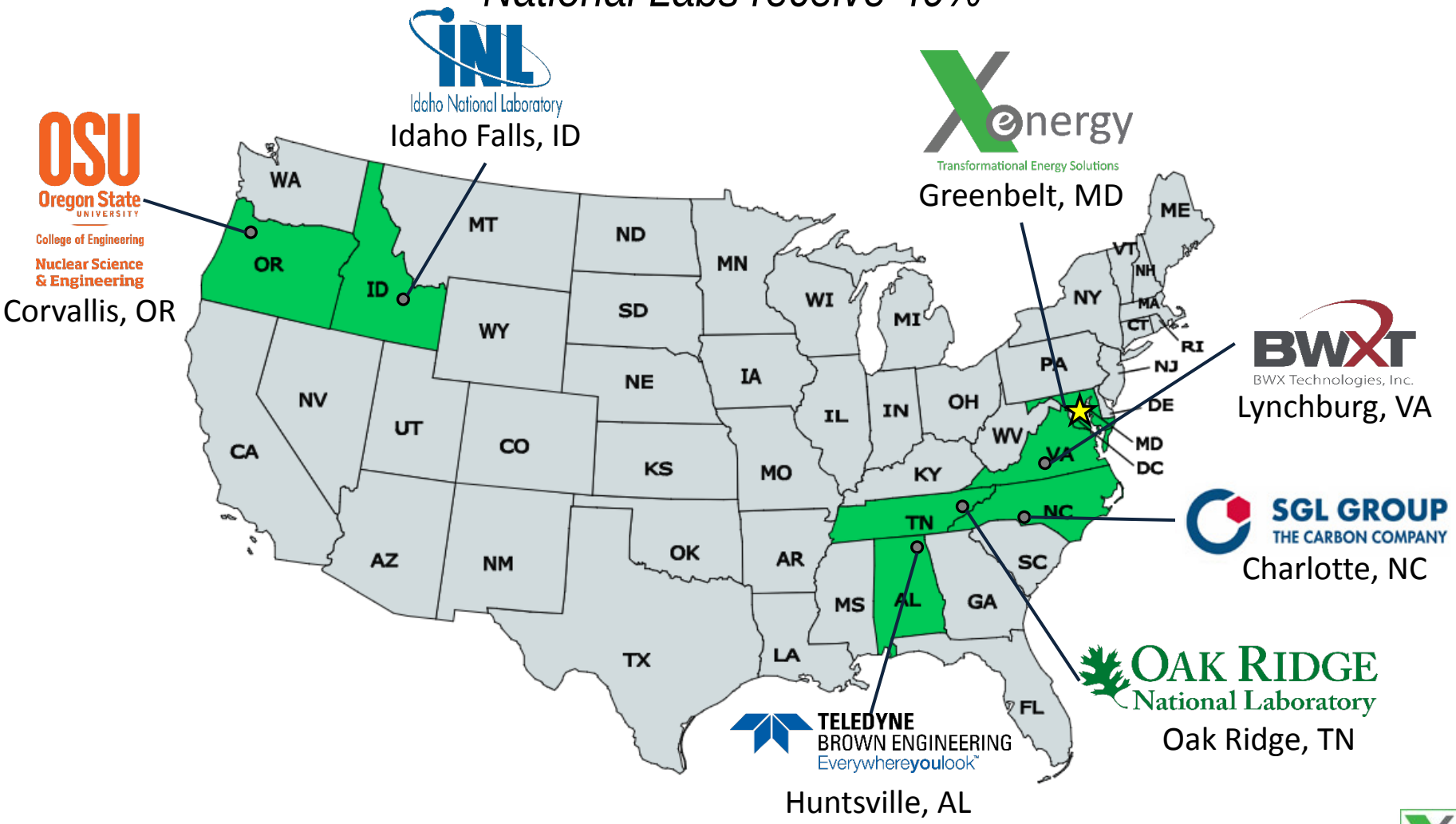
- Five (5) year, $53M (Cost share - $40M DOE and $13M private investment) Cooperative Agreement for short-term development activities that will enable deployment of the Xe-100 reactor in the 2030s
  - **Reactor Design Furtherance –** Heat transfer modeling; Graphite qualifications
  - **Fuel Development** - Establish a U.S. manufacturing capability at laboratory and engineering scale
  - **NRC Engagement –** White papers and topical reports to improve NRC technology familiarity
- X-energy's project builds on the DOE Next-Generation Nuclear Plant (NGNP) and Advanced Gas Reactor (AGR) programs
- X-energy's experienced team includes: BWXT, Teledyne Brown, Idaho National Laboratory, Oak Ridge National Laboratory and Oregon State University

X-energy's goal is to produce a demonstration plant by 2030 – five years ahead of the DOE requirement

X-energy Leveraging a Proven Team

5-year, $53M cost-share Cooperative Agreement

National Labs receive 40%



Conclusions

- X-energy has conceptualized the Xe-100, an innovative design through simplification, reduced technical and licensing risks
- The Xe-100 reactor is designed to meet utility/user requirements, whilst adhering to the NRC regulatory requirements
- The Xe-100 concept is intrinsically safe, cost efficient, proliferation resistant and can be fully produced within the bounds of the U.S.
- Apart from the business case for the Xe-100 reactors in the US, X-energy aims at utilizing the U.S. industry to its fullest extent in providing a standard, cost-efficient energy solution world-wide

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